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3D-analysis of the spay test 101 in the TOSQAN facility using GASFLOW II

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1. Introduction

During the course of a hypothetical severe accident in a PWR, hydrogen can be produced by the reactor core oxidation and distributed into the reactor containment according to convection flows and water steam wall condensation. In order to prevent the overpressures in the event of a steam break, spray systems are used in the containment. However, the effect of a spray could even increase the risk of hydrogen explosion by condensing steam and therefore locally enriches hydrogen in gaseous mixtures. Thus, detailed understanding of the 3D thermal hydraulic conditions inside the containment is of high relevance for all aspects of accident management and mitigation. The computer code GASFLOW II has demonstrated its ability in the past to calculate the important thermal hydraulic processes during such severe accident sequences [1]. GASFLOW gives a time dependent solution of the 3D Navier Stokes equations in cylindrical or cartesian coordinates. The validation of the code with scenario related 3D experimental data is required to use this code as a predictive tool for the simulation of such accidents in real reactor containments and for the design and verification of mitigation measures. Validation is therefore an essential part of code development.The validation of GASFLOW have focused on more recent experiments in the new containment test facilities ThAI, TOSQAN, and MISTRA [2]. They have innovative 3D instrumentation for the validation of results from 3D CFD simulations. GASFLOW blindly predicted the pressure and temperature distribution for a MISTRA experiment and for the ThAI benchmark experiment TH7 quite well [3]. The 3D experiment TH7 was performed without hydrogen release in a multi compartment geometry of the ThAI facility and involved a sequence of eccentric steam injections at high and low injection points followed by a heating phase. Also, the-state-of-art tests of the open TOSQAN benchmark (ISP 47) was analyzed with GASFLOW in a 2-D cylindrical geometry [4]. Recently the French organization Institute de Radioprotection et de Surete Nucleaire (IRSN) in Saclay have performed a series of spray tests in TOSQAN test facility.

2. TOSQAN tests and GASFLOW modeling

The TOSQAN project has been created to simulate separate-effect tests representative of typical accidental thermal-hydraulic flow conditions in the reactor containment. The idea of the TOSQAN spray program is to perform an intermediate study between separate-effect tests and integral tests, considering gas-spray interaction, with a high density of instrumentation. The TOSQAN facility (Fig. 1) is a closed cylindrical vessel (7 m^3, i.d. 1.5 m, total height of 4.8 m) into which steam or non-condensable gases can be injected. The spray test 101 was simulated with GASFLOW and the results were compared with those by GOTHIC code.

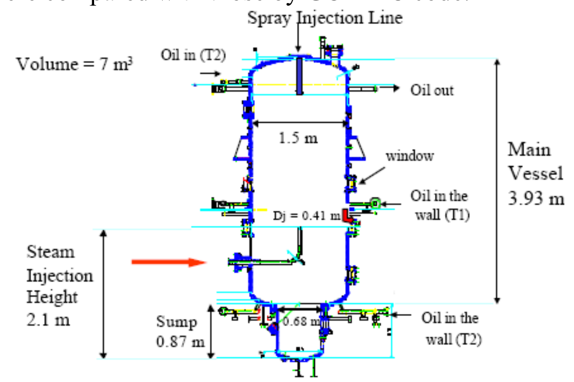

Fig. 1 Schematic view of TOSQAN facility

2.1 Test conditions

The initial conditions are as followed: 120 ℃ wall temperature that is assumed to be constant during the whole test, air-steam mixture with relative humidity of 70 %, in which the mixture is assumed to be initially homogeneous, initial total pressure of 2.5 bars. The injection point of the spray is located on the vertical symmetry axis, at a distance of 70 cm from the top of the vessel. The spray water is injected in the downward direction. The spray boundary conditions are as followed: water spray flow rate of 30 g/s, water spray temperature of 20 ℃ at the injection, total spray angle of 55 °, spray injection velocity of 3 m/s, and droplet diameter of 200 μm. The vessel is heated up to 120 ℃ before the test day and steam injection is performed in the vessel containing one bar air at 120 ℃, until total pressure of 2.5 bars is reached. After reaching a total pressure of 2.5 bars, steam injection is stopped. The water spray injection is started at a constant flow rate and a constant injection temperature. The test is stopped when the pressure decrease goes near zero.

2.2 GASFLOW modeling

TOSQAN test 101 was modeled three dimensionally in cylindrical geometry as shown in Fig. 2. 12 sections

(30 degree for each one) in the azimuthal dimension, 10 sections in the radial dimension, and 48 sections in the vertical dimension were used. Total 5,760 nodes for the test were applied in GASFLOW simulation. For the spray actuation, normal water of 293 K was introduced at the rate of 30 g/sec and the droplet size was about 0.013 cm.

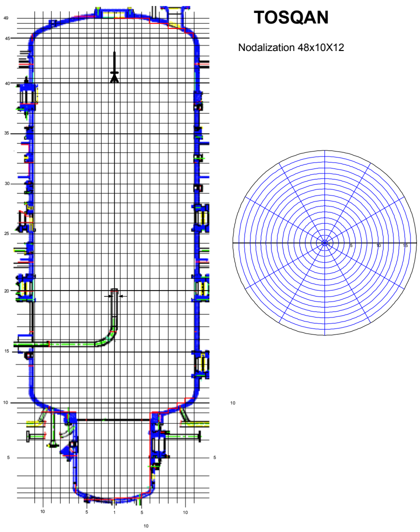

Fig. 2 Vertical and horizontal view of 3D nodalization

Spray modeling assumes a mechanical equilibrium between gas and drops (same velocity for both phases). Concerning the thermal part, a specific internal energy equation for the droplet is added, and the gas temperature is computed by subtracting the droplet energy from the total energy equation and inverting this relationship for the gas temperature; the specific internal energy equation is also inverted to get the droplet temperature. The mass transfer is modeled to represent the droplet evaporation in the gas and condensation of steam on droplets. A droplet “sink” term is added in a so-called “droplet depletion model”: it is either a parametric model (bulk rainout) or a mechanistic model (droplets impacting the walls); the first one is used here to “simulate” droplet evaporation on the walls.

3. Validation results

The thermodynamical global behavior concerns the pressure variation in the TOSQAN vessel. Results for the total pressure at the final equilibrium are presented on Fig. 3. Simulation results of GASFLOW for the test 101 shows lower pressure transient than the test result. This evolution is shown to be a same trend in the case of GOTHIC calculation. The depressurization in TOSQAN test 101 is overestimated by the both calculations. Time evolutions of gas temperatures close to the spray injection point (Z14) are given on Fig. 4. GASFLOW result shows the same behavior in comparison with test data but there is a little difference. Maybe this temperature trend is assumed as a result from the over-depressurization in the calculation.

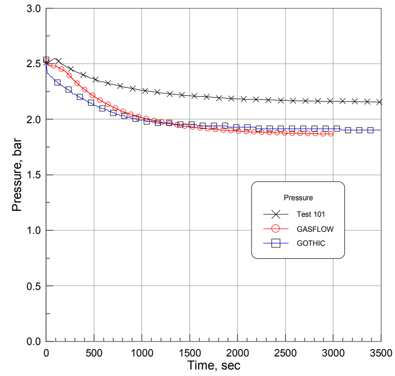

Fig. 3 Comparison of the total pressure transient

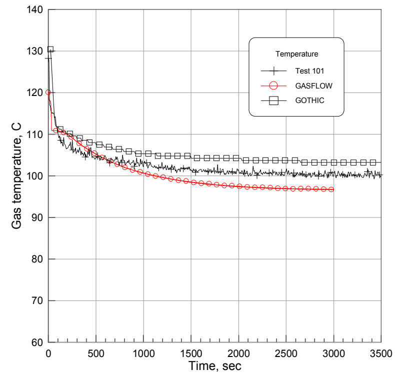

Fig. 4 Comparison of the gas temperature at Z14/R12

4. Conclusion

A validation exercise on TOSQAN spray test 101 was performed through 3D CFD code GASFLOW and its results, also, was compared with the results of a 3D code GOTHIC. The test was predicted well by GASFLOW although there was a little difference in the time evolution. The depressurization overestimated by the calculation could mainly be due to the droplet vaporization between the gas-walls. Reconsideration for a complete heat and mass transfer model of the spray droplets is need farther, including the steam condensation on droplets and the steam production due to droplet vaporization in the gas and/or on the walls.

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